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The Impact of Role Assignment on Students' Social-Cognitive Engagement in K-12 Collaborative Learning: A Network Analysis Approach

Peng Chen

pengchenbnu@163.com

Capital Normal University

Lu Liu

Capital Normal University

Xiaya Liu

Capital Normal University

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Abstract

Collaborative learning has become a widely adopted pedagogical model in K-12 education, yet ensuring active participation of all learners remains a persistent challenge. Role assignment is regarded as a promising strategy to promote engagement by encouraging learners to take responsibility in group tasks. This study explores the impact of role assignment on students' social-cognitive engagement in collaborative learning within an information technology course. Sixty middle school students participated in the study, with 30 assigned to collaborative learning with specific roles and 30 engaging in group learning without role assignment. Dialogue audio and video data were collected throughout the collaborative activities and analyzed using social and cognitive network analysis to capture patterns of interaction and knowledge construction. The results indicate that role assignment significantly enhances students' social-cognitive engagement and that learners in different roles exhibit distinct patterns of engagement. These findings provide empirical support for role assignment as an effective strategy to foster student participation and meaningful knowledge building in technology-enhanced classrooms.

1 Introduction

Collaborative learning refers to an educational method in which two or more students share knowledge and skills through interaction, collaboration, or discussion, solving problems, completing tasks, or achieving goals together to promote knowledge construction (Arnau-González et al., 2025; Gardeli & Vosinakis, 2025; Zhang et al., 2025). Collaborative learning has been shown to foster students' computational thinking (X. Lai et al., 2023), critical thinking (E. Xu et al., 2023) and creativity (Kusumawati et al., 2019). It also enhances learning outcomes (Labonté & Smith, 2022) and improves collaboration and interpersonal communication skills (S. C. Yang & Liu, 2005). When applied to programming, collaborative learning can further boost students' programming quality (Jose De Faria et al., 2006) and speed (Williams et al., 2000).

Role assignment is a widely used strategy in collaborative learning, providing students clear guidance on how to engage in discussions to support their thinking and group interaction (W. Xu & Dai, 2025). This approach enables students to develop a variety of skills by taking on different roles (Karal et al., 2024). Role assignment strengthens interdependence within collaborative learning and facilitates the distribution of responsibilities among group members (Gu et al., 2015; Karal et al., 2024). Previous studies has also shown that role assignment in collaborative learning generally has a positive impact (K.-Z. Chen & Yeh, 2021; Feng et al., 2021; Liu et al., 2025; Strijbos et al., 2007).

Learning engagement has been a key target for interventions and a primary goal in many schools improvement programs (D. Yang et al., 2022). Researchers have identified both cognitive and social dimensions as crucial for collaborative learning research, pedagogy development, and technology use (Ouyang & Chang, 2019). Most studies define cognitive engagement as students' knowledge sharing, construction, and creation levels (Van Aalst, 2009), while social engagement refers to students' interaction patterns with peers (Ouyang, 2021). Some research suggested a positive connection, where

socially active learners show deeper cognitive engagement (e.g., Tirado et al., 2015). However, other studies present a more nuanced view, revealing that even peripheral, low-performing students could initiate social interactions and construct knowledge (e.g., Vaquero & Cebrian, 2013).

This complexity highlights the need for further research into students' social cognition and engagement as they assume different roles in collaborative learning. Role assignment typically provides students with specific instructions on how to participate in discussions, guiding their behavior throughout the collaborative learning process (Strijbos et al., 2007). Role scripts are often pre-designed to define participants' the roles, behaviors, and activity sequences, thereby structuring the learning process (Şeyh et al., 2023). A key question is whether learners assigned fixed roles in collaborative learning—such as initiator, moderator, debater, resource searcher, and summarizer (De Wever et al., 2010)—demonstrate similar or different levels of cognitive and social engagement. Most previous studies have focused on online discussion environment, with learners predominantly being undergraduate students in higher education. However, there is relatively little research on the classroom environment in secondary education, especially in information course. Therefore, this study centers on two dimensions of learning engagement—cognitive engagement and social engagement—to explore the impact of role design on collaborative learning in the secondary education classroom environment. We pose the following two research questions:

(1) Does the role assignment strategy affect learners' socio-cognitive engagement in collaborative learning?

(2) What are the characteristics of socio-cognitive engagement among learners with different roles in collaborative learning?

2 Literature review

2.1 Role assignment in collaborative learning

Johnson et al. (1994) define collaborative learning as an instructional approach that utilizes small groups, enabling students to collectively enhance their learning and comprehension. Prior studies have investigated the advantages of collaborative learning, including the enhancement of academic performance (e.g., Garcia-Sanjuan et al., 2018; Molinari, 2017), improvement of problem-solving abilities (Chi & Wylie, 2014; Miyake, N. & Kirschner, P. A., 2014; E. Xu et al., 2023), and augmentation of student motivation (e.g., Enache & Crisan, 2013). Meanwhile, researchers also have identified various factors that can affect the quality of collaborative learning, including role assignment (Gu et al., 2015; Wang et al., 2024; E. Xu et al., 2023), activities (e.g., Schellens & Valcke, 2005), activity scaffolding (e.g., Freydis Vogel et al., 2017), and students' motivation (e.g., Knoche, 2022), etc.

Role assignment, a significant aspect affecting collaborative learning, has garnered the interest of many researchers. Morris et al. (2010) describe roles as functions that direct individual behavior and facilitate group collaboration. Role assignment is a scripting technique that provides students with explicit

directives for participating in detailed instructions on how to engage in conversations, thereby augmenting their cognitive processes and collaborative interactions (Strijbos et al., 2007). Şeyh et al. (2023) characterized role assignment as a framework intended to enhance group members' behavior and interaction. To ensure the quality of learning, it was essential to predefine the roles, behaviors, and sequence of activities for participants. Consequently, numerous researches have explored the impact of distinct role assignments on group dynamics and outcomes. Cesareni et al. (2016) established a four-role framework comprising a social mentor, an integrator, a concept mapper, and a skeptic. De Wever et al. (2010) delineated five roles in online collaboration: initiator, moderator, debater, resource searcher, and summarizer, and examined their influence on participants' perceived transactional distance and knowledge sharing behaviors. Raija H. Hämäläinen et al. (2018) investigated the correlation between different character types and collaborative knowledge construction as students' progress through 3D instructional games, utilizing game mechanics. Uz-Bilgin et al. (2020) examined the collaboration of explorers and navigators in cooperative learning. Understanding the characteristics of virous roles in collaborative learning is essential for improving its quality and efficacy. Consequently, this research investigated the learning engagement linked to role assignment in collaborative learning.

2.2 Learning engagement in CSCL

Learning engagement is a vital element that influences students' academic achievement, cognitive development, and the overall quality of their education (Kahu & Nelson, 2018; Karen C. H. Zhoc et al., 2018). It is widely recognized as a complex phenomenon encompassing cognitive, behavioral, emotional, and social dimensions. It embodies a synthesis of the socio-emotional and cognitive aspects of learning (Fredricks et al., 2004).

2.2.1 Cognitive engagement in CSCL

Zhu et al. (2024) describe cognitive engagement as the intellectual effort necessary for knowledge construction and problem-solving. Sinha et al. (2015) and Zhou and Ye (2024) regarded it as a process of collaboratively constructing knowledge towards a certain goal. Altmetric et al.(2017) view it as students' focused attention while constructing their own knowledge. Bloom and B.S (1956) categorized cognitive behaviors into six level: remembering, understanding, applying, analyzing, evaluating, and creating, with increasing cognitive demands from remembering to creating. Similarly, students' cognitive engagement progress from lower to higher levels during learning. The ICAP framework distinguishes cognitive engagement from behavioral activities, outlining four stages: Passive, Active, Constructive, and Interactive, which correspond to the four stages of knowledge transformation (Chi & Wylie, 2014). The four categories of cognitive engagement, ranging from passive to interactive, signify an escalating degree of involvement. The result of lower-level cognitive processes establishes the foundation for higher-level cognitive processes. In turn, higher-level cognitive processes enhance and expand the outcomes of lower-level cognitive processes. Cognitive engagement in the learning process progressively indicates the learner's comprehension and utilization of knowledge. Increased cognitive engagement correlates with improved learning outcomes.

The common methods for analyzing cognitive engagement are questionnaires and content coding. Barlow et al. (2020) used a scale to assess students' cognitive engagement in class, while Li et al. (2025) developed a scale to explore the relationship between courage, optimism, cognitive engagement, and communicative willingness in a specific field. However, the questionnaire method is rather subjective. Consequently, researchers evaluate learners' cognitive engagement by categorizing data from the learning process. For example, Giessler (2024) explored EFL writers' cognitive engagement with AWE feedback through screen recording coding, and B. Xu et al. (2020) used content analysis to examine how teacher roles affect learners' engagement in online discussions. Cognitive engagement is dynamic, and over the past decade, network models temporally and interdependently connected phenomena have been developed using epistemic network analysis (ENA). This approach quantitatively models discourse in various activities(Csanadi et al., 2018). Ye and Zhou (2024) used ENA to investigate the relationship between learning emotions and cognitive processes in online collaborative learning, while Guo et al. (2023) explored how cognitive engagement varies with the level of interaction. In this study, ENA was employed to investigate the impact of role assignment on learners' cognitive engagement in collaborative learning.

2.2.2 Social engagement in CSCL

Recognizing the role of interaction in learning engagement, Fredricks et al. (2004) introduced a social dimension to the existing framework of cognitive, behavioral, and emotional engagement. Patrick et al. (2007) defined social engagement as the social interactions that students participate in their learning, while Sinha et al. (2015) viewed it as the quality of group interaction while completing tasks. Social engagement is often measured by peer interactions. For instance, Lu and Churchill (2014) found that social interactions within a Social Network Environment (SNE) led to a denser social network structure, enhancing students' social engagement. Researchers have also studied social engagement in online learning environments, including learner communities (Barak & Rafaeli, 2004), online forums (Barak & Dori, 2009; Miri Barak, 2012), and Web 2.0 applications (Barak & Ziv, 2013). However, most studies have focused on online settings, with less attention to the classroom context.

Various methods, such as network analysis and content analysis, are used to examine social engagement. Liem and Chong (2017) designed a learning analysis kit that combined social network and lexical analysis, finding that active students had better peer interaction and engaged more deeply in learning. Zhu et al. (2021) used Social Network Analysis (SNA) to study learner interactions, and Ouyang et al. (2021) employed a mixed-methods approach that combined social network analysis, content analysis, and cognitive network analysis to investigate the impact of student-oriented learning analytics (SLA) tools on engagement. In collaborative learning, social engagement is often reflected through learner interactions, and the social networks formed can reveal a group's information sharing and cohesion. Therefore, this study employed SNA to examine social engagement in classroom collaborative learning, specifically focusing on the impact of role assignment.

3 Research design

3.1 Research context and participants

The study was conducted in an information technology course at a middle school in Beijing, China, with the course content concentrating on “Arduino Intelligent Control”. The course lasted for a total of 6 weeks, comprising two 40-minute lessons each week. The teacher utilized the Mind+ platform and an Arduino hardware kit to facilitate project-based learning, with the objective of enhancing students’ computational thinking abilities. The Mind+ graphical programming environment (Fig. 1 (a)) was used in this course for programming, while Arduino hardware kits (Fig. 1 (b)) were assembled to execute the intended functions.

Sixty seventh-grade students from two classes participated in this study. Because the course is an elective, there were no restrictions on students’ gender when choosing it. The experimental group consisted of 30 students, comprising 28 boys and 2 girls, whereas the control group included 30 students, comprising 27 boys and 3 girls. Both classes were instructed by the same teacher utilizing identical course material. At the beginning of the course, students were randomly allocated to groups, each including 5 individuals. The experimental group and the control group each had six subgroups. All experimental procedures involving student volunteers in this research were conducted ethically. The investigators were permitted to conduct experiment after obtaining permission from the school and its instructors.

The 6-week curriculum was segmented into two phases, advancing from simpler to more complex tasks. During the first phase (weeks 1–4), the instructor employed traditional lecturing methods to deliver course (Fig. 1 (c)) and instructed the groups to complete tasks collaboratively (Fig. 1 (d)). In this phase, each group accomplished three tasks: controlling LED lights and sensors, operating the steering gear via an infrared remote control, and controlling LCD screens. During the second phase (week 5–6), each group utilized Mind + and Arduino kits to design and fabricate an artifact, such as smart trash cans, anti-theft alarms (Fig. 1 (e) & Fig. 1 (f)).

3.2 Role assignment for experimental group

This study identified five roles-Recorder, Analyzer, Organizer, Operator, and Programmer-based on studies concerning role design and the context of the curriculum content (Gu et al., 2015; Strijbos et al., 2007; Strijbos & Stahl, 2007).

The recorder documents the crucial information from the class lecture and the significant points from group discussions. By structuring the information, they assist team members in addressing issues pertaining to the organization and retention of knowledge. They contribute their insights and aid in resolving issues. The analyzer assists students in surmounting obstacles related to logical thinking, algorithm application, and creative problem-solving by facilitating their comprehension of task specifications, situational analysis, and solution formulation. The Analyzer promotes critical thinking among team members when confronted with problems, enhancing the overall quality of the group’s

project execution. The organizer monitors the efficient distribution and management of team assignments, guaranteeing timely completion. They can assist team members with low self-management, responsibility, and collaboration spirit, while also fostering communication and cooperation among team members to ensure the project is completed on schedule. The programmer aids students in resolving technical issues in programming by converting solutions into code and debugging them for optimal performance. This role also promotes comprehension and use of programming languages and algorithms. In order to overcome the group's shortcomings in hardware operation experience, the Operator works closely with the programmer to guarantee that circuit connections are proper and that the program runs smoothly. Since every role in this study has the capacity to perform specific leadership duties, no official leader role has been assigned. It removes an authority-based hierarchy and guarantees that all responsibilities are more equal.

Students in the experimental group were given the opportunity to select one or two roles to play after the teacher had explained the traits of each role to them prior to the experiment. Then, they completed the VARK learning style questionnaire (Leite et al., 2010). This questionnaire thoroughly evaluates students' sensory preferences in four areas: Visual, Aural, Read-Write, and Kinesthetic. It was created using Neil Fleming's VARK learning style paradigm (Fleming et al., 2006), which focuses on how learners establish their learning styles through the use of many senses. Its usefulness and practicality and guidance have been widely acknowledged (El-Saftawy et al., 2024; Mozaffari et al., 2020). The questionnaire consists of 16 items and has a good level of reliability and validity (Cronbach's alpha > 0.85). This study assigns roles to students based on their selections and learning styles. Table 1 lists each learning style's attributes as well as the role-matching correlations that go with it.

Table 1
Overview of VARK Learning Styles, Characteristics, and Roles.

Learning Style	characteristics	Role
Visual	Learners prefer to learn through texts, charts, pictures and videos. They like using visual aids, reading, and watching presentations.	Programmer Organizer
Aural	Learners are more likely to learn by listening and speaking. They enjoy listening to lectures and recordings, participating in discussions, and giving verbal explanations.	Analyzer Organizer
Read-write	Learners prefer to learn through reading and writing. They enjoy using writing to arrange their ideas.	Recorder
Kinesthetic	Learners learn through hands-on activities and tactile experiences. They prefer to learn through practice.	Operator

3.3 Procedures

The research procedure of the study is illustrated in Fig. 2. The experimental group was composed of groups with role assignment, while the control group comprised groups without role assignment. Before

the experiment, each student in the experimental group was assigned a specific role type within their group. They participated in collaborative tasks according to their assigned roles, whereas students in the control group completed the tasks freely.

During the 6-week experiment, students collaborated to complete three tasks and one project, while the researcher collected video and audio recordings of their collaborative process. By the end of the experiment, both the experimental group and the control group had accumulated 30 hours of video and audio recordings, which were used as research data for this study. Additionally, the teacher assigned project scores to each group.

3.4 Data analysis

3.4.1 Data analysis method and procedures

This study collected 60 hours of audio and video data from both the experimental and control groups, which was transcribed into approximately 62,460 words of text.

The first step in the data analysis was coding. The study used complete student utterances as the smallest unit of analysis, with transcription and coding conducted in Excel. A total of 4,452 valid utterance units were obtained, including 2,302 from the experimental group and 2,150 from the control group. To ensure coding reliability, two team members received coding training. They independently coded the dialogue texts from four groups (two control groups and two experimental groups). The Cohen's Kappa value between the coders was 0.849, indicating high reliability (Fleiss, 1981). The remaining data were split into two halves, with each part coded separately. Any disagreements in coding were discussed and resolved by the coders until a consensus was reached.

This study employed a mixed-methods approach, including epistemic network analysis (ENA) and social network analysis (SNA), to examine the impact of role assignment on social-cognitive engagement in collaborative learning. For the first research question, the study compared the social-cognitive engagement between the experimental and control groups. For the second research question, we analyzed the social-cognitive engagement data from different roles within the experimental group, comparing the characteristics and differences across these roles. Additionally, the study adapted the project evaluation rubric developed by Besemer et al. (1981), assessing projects in three dimensions: innovativeness, applicability, and completeness, with weights of 30%, 40%, and 30%, respectively, for a total score of 100 points. Six teaching assistants evaluated the project, and the Kendall W coefficient was 0.8, indicating good reliability.

3.4.2 Coding framework

Based on Chi's ICAP framework (2014) and the practical context of the information technology curriculum, this study developed a coding scheme for cognitive engagement. The coding focused on interactions related to the learning materials and thematic tasks, excluding irrelevant dialogues. Table 2

presents the dimensions, subcategories, definitions, and examples of the coding scheme used in this study.

Table 2
The coding scheme for cognitive engagement.

Dimension	Subcategory	Definition	Example
Passive	Acceptance (PA)	The learner acquires information from learning materials but remains silent for a long time, only responding after being prompted by teacher or peers.	Okay, I'm here.
Active	Repetition (AA)	The learner directly copies or cites content from the materials.	The buzzer is D2.
	Emphasize (AB)	The learner concentrates on or highlights a specific part of the learning material.	What's yellow for? Connect the digital pins.
	Summary (AC)	The learner summarizes and integrates existing information.	Read the infrared receiver module, follow the advanced instructions, and set any pin randomly. Then, repeat the execution.
Constructive	Question (CA)	The learner proposes a new question based on their understanding and seeks possible solutions from other members.	Why is there no pause in the middle?
	Elaboration (CB)	The learner provides suggestions, explanations, or perspectives beyond the materials, using examples or other methods.	Actually, I have a suggestion. If we change it to 2, we could play another song and make it simpler.
	Analysis (CC)	The learner presents analytical or comparative viewpoints or responds to questions posed by other members.	Read the infrared digital module. Digital pin 6. Let's check if there's a suitable location for it. Oh, I just plugged it in the wrong one, so let's replace it.
	Contrast (CD)	The learner offers argumentative analysis or shares external materials by comparing different contents.	Check if the frequency is not adjusted correctly; just turn it on. I keep it on all the time. Is there a poor connection? We had a poor connection earlier. I just kept pressing it.
Interactive	Support (IA)	The learner agrees with others' ideas or viewpoints.	What do you think of this shell? ——Okay.
	Establishment (IB)	After reaching an agreement on a viewpoint, the learner develops a new perspective based on others' opinions.	I know, then just put it directly into this loop execution.

Dimension	Subcategory	Definition	Example
	Defense (IC)	The learner challenges others' viewpoints and defends their own perspective through debate.	No, we can only execute that after this one. We need to set its priority higher to ensure we can repeat the execution without any issues.

4 Results

4.1 Does the social-cognitive engagement differ between the EG and CG?

4.1.1 Comparison of the social engagement between groups

To address RQ1, the study collected and analyzed the discourse data from both the experimental and control groups. The group interaction matrices were imported into the UCINET 6.0 for social network analysis, using three key metrics—network density, average weighted degree, and reciprocity—to assess social engagement. Network density reflects the extent of communication among members, with higher density indicating more extensive direct connections. The average weighted degree measures the strength of communication ties, where higher values signify more frequent interactions and deeper relationship. Reciprocity measures bidirectional communication, with higher reciprocity indicating more balanced interactions.

As shown in Table 3, the network density for the experimental group ranged from 10.90 to 16.65, while the control group ranged from 7.50 to 12.58. The intra-group member relationships of the experimental group were significantly superior to those of the control group. The experimental group's weighted degree varied between 27.60 and 62.60, whereas the control group's range of 22.50 to 42.75. It indicated the experimental group was more connected and communicated more frequently. In contrast to the control group, which had reciprocity values ranging from 0.67 to 1.00, the experimental groups had reciprocity values above 0.9, with four of them achieving a score of 1.00. It suggested that there was more balance in the communication within the experimental groups.

Table 3
Statistics of the overall social engagement of the control group and experimental group

Group	Network Density		Weighted Degree		Reciprocity	
	CG	EG	CG	EG	CG	EG
1	8.58	16.65	30.75	62.60	0.72	1
2	12.50	10.90	37.50	27.60	0.95	0.90
3	7.50	14.35	22.50	57.40	0.67	1
4	11.50	15.50	34.5	62	0.80	1
5	12.58	12.35	42.75	41.40	1	1
6	11.83	12.30	35.50	45.20	0.83	0.95

Then, we used Shapiro-Wilk tests on all three parameters to determine if the role assignment significantly improved learners' social engagement in collaborative learning. The network density and average weighted degree data met the homogeneity of variance and normal distribution requirements. As shown in Table 4, an independent samples T-test was used to assess the differences between the EG and CG. The experimental group's network density (M = 13.68, SD = 2.19) was significantly higher than the control group's (M = 10.75, SD = 2.16), with a p-value of 0.042, indicating stronger connections within the experimental group. Additionally, the experimental group's nodes showed greater connectivity, with a significantly higher weighted degree (M = 49.37, SD = 13.81) compared to the control group's (M = 33.92, SD = 6.84), with a p-value of 0.034. This suggests that the role assignment positively influences network density and weighted degree in collaborative learning.

Table 4
Independent sample t-test of the social network in the experimental group and the control group.

Social Input Index	Mean(SD)		Independent sample t-test	
	Experimental Group(N = 6)	Control Group(N = 6)	t	Sig.
Network Density	13.68(2.19)	10.75(2.16)	2.328	.042*
Weighted Degree	49.37(13.81)	33.92(6.84)	2.455	.034*

Since the reciprocity index did not follow a normal distribution, the Mann-Whitney U test was utilized to determine whether there was a difference between EG and CG. Table 5 demonstrates that the experimental group's reciprocity (RSR = 8.58, rank sum = 51.50) is significantly higher than that of the control group (RSR = 4.42, rank sum = 26.50), with a p-value of 0.038 (< 0.05). Thus, significant differences in network density, average weighted degree, and reciprocity were observed between the

experimental and control groups, indicating that role assignment positively influenced social engagement

Table 5
Mann-Whitney U test of the social network in the experimental group and the control group.

Social Input Index	RSR(rank-sum)		Mann-Whitney U Test	
	Experimental Group(N = 6)	Control Group(N = 6)	z	Progressive Saliency (two-tailed)
Reciprocity	8.58(51.50)	4.42(26.50)	2.328	.038*

4.1.2 Comparison of the cognitive engagement between groups

We analyzed the cognitive engagement of both the control and experimental groups, with results shown in Fig. 3. The control group scored significantly higher in Acceptance (PA), Repetition (AA), and Question (CA), while the experimental group exhibited much greater involvement in Summary (AC), Analysis (CC), Support (IA), and Establishment (IB), reflecting the Constructive and Interactive dimension of cognitive engagement. Thus, the experimental group demonstrated higher cognitive engagement, indicating that role assignment positively influenced student learning engagement. The Chi-square test revealed a significant difference in cognitive engagement between the CG and EG ($\chi 2 = 157.578$, $p < 0.001$).

The coding results for cognitive engagement were imported into Epistemic Network Analysis (ENA) (https://app.epistemicnetwork.org), generating cognitive network centroid distribution maps for both the EG and CG, as shown in Fig. 4. The red square represents the centroids of the control groups, while the blue square represents the centroids of the experimental groups. The dashed box outlines the 95% confidence interval for each centroid. An independent samples t-test showed no significant difference between the EG and CG on the Y-axis (t=.00, p = 1.00>.05). However, a significant difference was found on the X-axis (t = 8.98, p=.00*<.05), indicating that the EG significantly differs from the CG across multiple dimensions of cognitive engagement.

Figure 5(a) presents the overlapping cognitive network diagram for CG and EG (red and blue, respectively), while the Fig. 5(b) and 5(c) show the mean network for both groups. As seen in Fig. 5, the CG shows higher frequencies in Repetition (AA) and Question (CA), while the EG had higher frequencies in Summarize (AC), Elaborate (CB), Analysis (CC), and Defense (IC). This indicates that role assignment in collaborative learning led to higher cognitive engagement in the EG compared to the CG. The overlapping graph reveals that the CG had more co-occurrences in low-level cognitive engagement dimension, particularly in Question (CA)-Elaboration (CB) and Question (CA)-Repetition (AA). In contrast, the EG had more co-occurrences in high-level cognitive engagement dimensions, such as Elaboration (CB)-Analysis (CC), Elaboration (CB)-Defense (IC), and Summary (AC)-Defense (IC). This highlights the effectiveness of role assignment in fostering cognitive engagement during collaborative learning.

4.2 Characteristics and Differences Analysis of Social Cognitive Engagement in Different Roles

4.2.1 Comparison of the social engagement of different roles in EG

To examine variation in social engagement across different roles, our study analyzed five specific roles using three key metrics: degree centrality, clustering coefficient, and core degree. As shown in Table 6, within the experimental group, the programmer had the highest in-degree and out-degree, whereas the organizer had the lowest for both. The clustering coefficient indicates the density of a role's local network, with higher values signifying more frequent interactions with other members. However, the organizer had the highest clustering coefficient, indicating a need for frequent supervision or reminders to ensure members complete their tasks. The similar clustering coefficient values among the other four roles suggest comparable interaction frequencies and closely connected local networks. Analyzers and programmers showed high core degrees, while the organizer's core degree was notably low. These three indicators suggest that programmers and analyzers act as core members in group collaboration, while the organizer is positioned at the periphery, reflecting distinct patterns of social engagement across roles.

Table 6
Social engagement characteristics of five roles in the experimental group.

role	Out-degree	In-degree	Clustering coefficient	Core degree
Analyzer	63.00	56.67	10.60	0.56
Operator	43.33	60.67	11.90	0.32
Organizer	33.33	18.67	16.28	0.02
Programmer	58.83	55.17	10.93	0.47
Recorder	48.33	54.00	12.04	0.28

Based on core degree values, our study identified two core roles within each experimental group. As shown in Fig. 6, the primary core roles in most groups were either the programmer or the analyzer. Notably, in EG6, the recorder emerged as the core role, with the analyzer playing a supporting role.

Based on the project scores, the experimental groups were categorized into two high-performance, two medium-performance, and two low-performance groups. This social networks for each performance type were then visualized, as shown in Fig. 7. In high-performance groups (Fig. 7(a)), the programmer (PR), analyzer (AN), and recorder (RE) played key roles. EG1 and EG4 displayed consistent bidirectional interaction between the programmer (PR) and the analyzer (AN), along with unidirectional communication from the programmer (PR) to the operator (OP). Additionally, the organizer (OR) nodes

were notably small in both groups, indicating that members could execute their task independently without supervision or direction from the supervisor, reflecting the higher engagement levels of high-performing members.

In mid-performance groups (Fig. 7(b)), interactions mainly occurred among the analyzer (AN), operator (OP), and recorder (RE), with bidirectional interactions between the analyzer (AN) and operator (OP) being most prominent. In contrast, the programmer (PR) in these groups was not central, requiring other roles to take on programming.

In low-performance groups (Fig. 7(c)), the connections between nodes were much weaker, indicating infrequent interaction among roles. However, EG5 showed notable interactions between the programmer (PR) and the analyzer (AN). Overall, there were significant differences among different types of performance groups, though social networks within the same performance category shared common traits while displaying unique characteristics in each group.

4.2.2 Comparison of the cognitive engagement of Different Roles in EG

To investigate how different roles contribute to cognitive engagement, we analyzed the proportion of each role across four cognitive engagement dimensions, as shown in Fig. 8. The results revealed that the programmer and operator exhibited similar profiles, both mainly engaging in elaboration (CB), question (CA), and summary (AC) responses.

PA=Acceptance, AA=Repetition, AB=Emphasize

The frequencies and proportions for these two roles across these three dimensions were as follows: for the programmer, elaborate (CB) (n = 163, 29.74%), question (CA) (n = 119, 21.72%), summary (AC) (n = 72, 13.14%); for the operator, elaboration (CB) (n = 129, 28.17%), question (CA) (n = 93, 20.31%), and summary (AC) (n = 87, 19.00%). Both roles also showed notable engagement in the Constructive and Interactive dimensions: for the programmer, defense (IC) (n = 52, 9.49%) and analysis (CC) (n = 45, 8.21%); for the operator, defend (IC) (n = 35, 7.64%) and support (IA) (n = 20, 4.37%). This indicates strong proactive participation, allowing both roles to actively explore and complete assigned tasks while maintaining effective collaboration. However, engagement in establishment (IB) was low – 1.82% for the programmer and 1.31% for the operator – suggesting for improvement in innovative collaboration. Compared to the programmer and operator, the analyzer showed high engagement in elaboration (CB) (n = 188, 32.08%) and question (CA) (n = 97, 16.55%), along with significant involvement in defense (IC) (n = 81, 13.82%). This indicates the analyzer's proactively expression of ideas, soliciting feedback, and defending their perspectives during collaborative learning. However, the lower proportion of analysis (CC) (n = 50, 8.53%) suggests that it was not dominant for the analyzer. The organizer's cognitive engagement mainly focused on defense (IC) (n = 75, 28.63%) and elaboration (CB) (n = 62, 23.66%). This reflects the organizer's role in monitoring task progress, coordinating member responsibilities, and resolving conflicts. However, the low percentage of higher-order cognitive behaviors, such as analysis

(CC) at 3.44% and no involvement in contrast (CD), shows that the organizer's cognitive resources were largely directed toward task coordination and team cohesion rather than depth knowledge construction. The recorder's cognitive engagement primarily centered on elaboration (CB) (n = 96, 21.43%), summary (AC) (n = 82, 18.30%), and repetition (AA) (n = 54, 12.05%), indicating a focus on reinforcing knowledge through restating key points and synthesizing information. Notably, analyzers showed a significant shift towards elaboration (CB) and defense (IC) compared to programmers and operators, with a decrease in summary (AC) behavior. Organizers, in contrast to the other roles, exhibited a high proportion of defend (IC) and emphasize (AB) behaviors. Recorders displayed a higher proportion of repetition (AA) and summary (AC) behaviors compared to other roles. Overall, differences in cognitive engagement were observed across roles, with the role assignment strategy guiding students to engage in collaboration according to their specific tasks, resulting in observed differences in varying engagement patterns.

To analyze the cognitive engagement connections within each role, we conducted Epistemic Network Analysis (ENA) for all five roles, with results shown in Fig. 9. Larger nodes indicate higher frequencies of specific behaviors, while thicker lines represent more frequent connections between nodes. Figure 9 shows that programmers, operators, and analyzers all had strong connections between elaboration (CB)-question (CA), elaboration (CB)-summary (AC), and elaboration (CB)-analysis (CC). Additionally, analyzer revealed a strong connection between elaboration (CB) and defense (IC). These results suggest that these roles excel at problem-solving, identifying solutions, and engaging in elaboration, analysis, and summarization. The organizer's network diagram was relatively simple, primarily showing connections between elaboration (CB)- defense (IC), with other connections were weaker. This suggests that the organizer is responsible for task monitoring and conflict resolution during the collaboration. They reminded others to complete their tasks through elaboration or questioning. For the recorder, connections between behaviors were more evenly distributed, with slightly stronger links between elaboration (CB)-question (CA), as well as elaboration (CB)-summary (AC). It indicates that the recorder frequently confirms, outlines, and clarifies key information, providing thorough explanations and organized summaries. Overall, the Epistemic Network Analysis of the five roles reveals distinct cognitive network structures for each role, highlighting the influence of role assignment on learners' cognitive engagement.

5 Discussion

5.1 Role assignment facilitates learners' social cognitive engagement

The experimental results indicated that the role assignment significantly enhances learners' social-cognitive engagement in collaborative learning. Firstly, role assignment effectively facilitated the transition from lower-order cognitive behaviors to higher-order cognitive behaviors. The experimental group showed a higher proportion of cognitive engagement in the Analysis (CC) dimension, with a greater co-occurrence of Elaboration (CB)-Analysis (CC). This suggests that role assignment encouraged

students to engage in more critical thinking. These findings align with Slavin (2014), who found that groups using role assignment performed better on analytical tasks than those without.

Secondly, the role assignment strategy, by assigning learners specific roles (such as programmer, recorder, or operator), clarifies their cognitive division of labor and task objectives. However, ensuring that roles align with students' characteristics is crucial for fostering deep engagement in collaborative learning. This aligns with previous research. Herrington & Oliver (2000) emphasized that role assignment should be based on an analysis of learners' individual characteristics and needs. Similarly, Tomlinson (2017) suggested that roles should be assigned according to students' interests, learning styles, and abilities—for example, assigning students with strong logical skills as analysts and those with high creativity as idea generators. Hämäläinen & Häkkinen (2010) found that better alignment between roles and students' personalities led to deeper group discussions. Teachers should consider the various learning factors, such as the relationships between disciplinary characteristics, cognitive levels, and learning styles, to maximize the pedagogical effectiveness of role assignments.

Thirdly, assigning specific roles within the team significantly improved the quality and structure of internal interactions. Without role design, collaboration often becomes disorganized, with some learners participating passively due to lack of motivation, leading to lower network connectivity, reduced node influence, and less symmetrical interactions. In contrast, role design, through standardized responsibilities and interaction processes, ensures active participation from all learners, allowing them to contribute their cognitive resources. This greatly enhances collaboration efficiency and fosters deeper interaction among learners. Gu et al. (2015) suggested that role structure design promotes interdependence and individual accountability, while Tang et al. (2024) found that a balanced socio-cognitive structure in groups leads to more effective information sharing and negotiation.

5.2 The differentiation of socio-cognitive engagement across different roles in collaborative learning

Previous studies have explored the impacts of role assignment strategies on students' cognitive and social presence (Avcı, 2020; Şeyh et al., 2023). Consistent with these findings, the results of this study indicate significant differences in the socio-cognitive engagement characteristics of the various roles.

Firstly, in terms of social engagement, we observed that the students' social contribution was primarily confined to their assigned roles. The programmer demonstrated significant technical authority and proactive connectivity, taking the lead in initiating tasks and serving as the focal point for team discussions. The operator, however, was more reliant on others' instructions to complete hardware connections or program debugging. The analyzer occupied a middle position, functioning as both a "decision supporter" and "problem criticizer". The organizers, in contrast, remained on the periphery, failing to engage deeply knowledge construction. The recorder acted as a "bi-directional filter" for information flow. This aligns with the findings of Wang (2021), who noted that the recorder plays a crucial role in capturing and organizing information, transforming tacit knowledge into explicit

knowledge. The phenomenon of role emergence and rotation, as described by J.-W. Strijbos and Weinberger (2010), was rarely observed in this study.

Secondly, in terms of cognitive engagement, the cognitive strategies and behavioral of each role are driven by their specific functions, as well as by the interaction between individual thinking habits and task complexity. For example, the programmer's cognitive engagement centers on questioning for information confirmation and elaborating on technical logic and solutions. They are motivated to complete programming tasks and exhibit greater confidence, which aligns with the findings of Denner et al. (2014). However, the programmer shows limited higher-order cognitive engagement behaviors, such as Establishment (IB), which restricts their exploration of alternative solutions. Repenning et al. (2015) found that technically oriented students in collaborative programming focus more on solving problems directly (e.g., writing code) and less on reflective discussions. The operator's cognitive engagement is primarily centered on the connection between Summary (AC) and Question (CA), reflecting a practice-focused approach. While they ensure that tasks are carried out in a standardized manner, the low level of Establishment (CB) behaviors indicates limited potential for collaborative innovation. C.-F. Lai et al. (2021) observed that, in programming tasks, students tend to focus on operational details due to the task's structural demands and cognitive load.

Unlike the operator, the analyzer addresses contradictions by questioning, elaborating on solutions, and ensuring implementation through collaborative discussion, as noted by Yao Lu, et al. (2023). However, the analyzer tends to focus on immediate problem-solving rather than systematic logic, which boosts collaboration efficiency but limits the depth of knowledge construction. Future research could develop guiding frameworks to help analyzers shift from solving individual problems to adopting a systems thinking approach. The organizers focus on process management and task coordination, ensuring team effectiveness by maintaining order, clearly stating goals, and emphasizing key milestones. They monitor process, provides execution, and proposes improvements, aligning with Kobbe et al. (2007). However, the absence of higher-order cognitive engagement, such as Analysis (CC) and Contrast (CD), points to a lack of strategic diversity. The recorder primarily focuses on information integration through Summary (AC) and Elaboration (CB), enabling dynamic knowledge processing. As noted by Donatella Cesareni et al. (2016), the recorder stimulates knowledge construction by providing written information and high-level analysis. However, the recorder does not fully engage in the team's knowledge co-construction, with cognitive resources often concentrated on surface-level processing rather than deeper reflection.

6 Conclusion, Implications, and Future Directions

This study provides empirical evidence on the effect of role assignment on social-cognitive engagement in collaborative learning. Based on the findings, the following recommendations for role assignments are proposed, aimed at guiding and optimizing learning in the era of collaborative learning.

6.1 Implications

Firstly, to maximize the potential of each role, teachers should encourage equal participation across roles. Unequal participation can lead to information loss and diminish the benefits of collaborative learning (Y. Lu et al., 2023). According to Heinimäki et al. (2020), “opinion roles” may encourage more inquiries and related discussions, leading to deeper learning interactions. For example, to help the recorder capture the key points of the class effectively, teachers could train them in systematic recording techniques like mind mapping or keyword extraction. To enhance knowledge integration and dissemination, teachers could also organize regular sessions for recorders to present group findings and share strategies for information integration.

Secondly, teachers should provide targeted scaffolding and instructions for various roles. Assigning specific responsibilities can boost learners’ enthusiasm and initiative, increasing group interaction and fostering an interactive atmosphere (Li et al., 2024). For example, teachers can establish a phased feedback system for the programmer’s progress and involve the analyzer in suggesting ways to optimize code logic. This approach helps the programmer move from simply “completing the task” to “achieving high-quality functionality”. Regarding the analyzer’s responsibility, teachers can introduce cognitive tools such as fishbone diagrams, the 5W1H framework, mind maps, and the SWOT analysis to improve their task decomposition and problem-solving skills.

Thirdly, teachers can implement a role rotation strategy within groups, allowing students to take on different roles over time. Imbalanced role distribution may result in an overload of core roles and neglect of peripheral ones. Heinimäki et al. (2020) suggested that guiding role transitions can refine group composition and help the group solve problems more effectively. Furthermore, Chen et al. (2020) argued that dynamic grouping strategies balance group composition and improve group collaboration effectiveness.

6.2 Limitations and future directions

Several limitations of the study could be addressed in future research. Firstly, the sample size in this study was small for both the experimental and control groups. A larger sample size could enhance the generalizability of the results. Additionally, the participants were selected from a course using convenience sampling, which may not fully represent the broader middle school student population, limiting the generalizability of the findings.

Secondly, the six-week duration of the study may have restricted the ability to observe dynamic changes in learners’ socio-cognitive engagement over time. Future research could extend the study duration and collect interaction data at different stages, offering a clearer view of the temporal dynamics of socio-cognitive engagement across different roles. A longer study period would also allow for the inclusion of role rotation strategies, which could enhance learners’ socio-cognitive engagement through dynamic grouping. Lastly, this study analyzed discourse data from learners’ collaborative processes using video and audio recordings. Future research could incorporate artificial intelligence technology to accurately capture and automatically analyze individual language and behaviors during programming. This would allow for a more comprehensive examination of socio-cognitive engagement across different roles.

Declarations

Author Contribution

Conceptualization, P.C.; methodology, L.L. & X.L.; writing —original draft preparation, L.L. & X.L.; writing—review and editing, P.C.; visualization, P.C. ; project administration, P.C. ; funding acquisition, P.C. All authors have read and agreed to the published version of the manuscript.

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Figures



Figure 1

The software, hardware, and In-class photos.

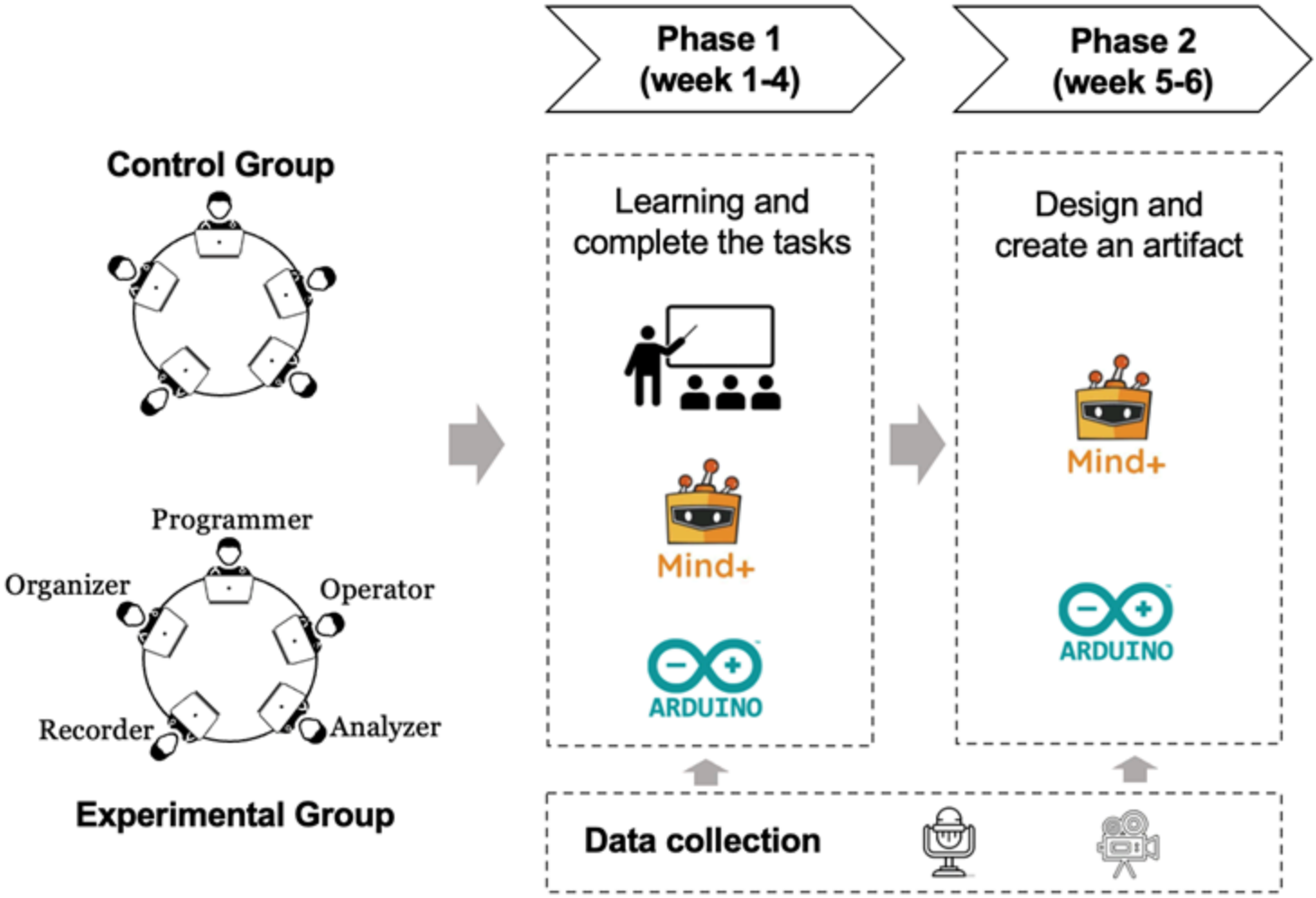


Figure 2

Research procedures.

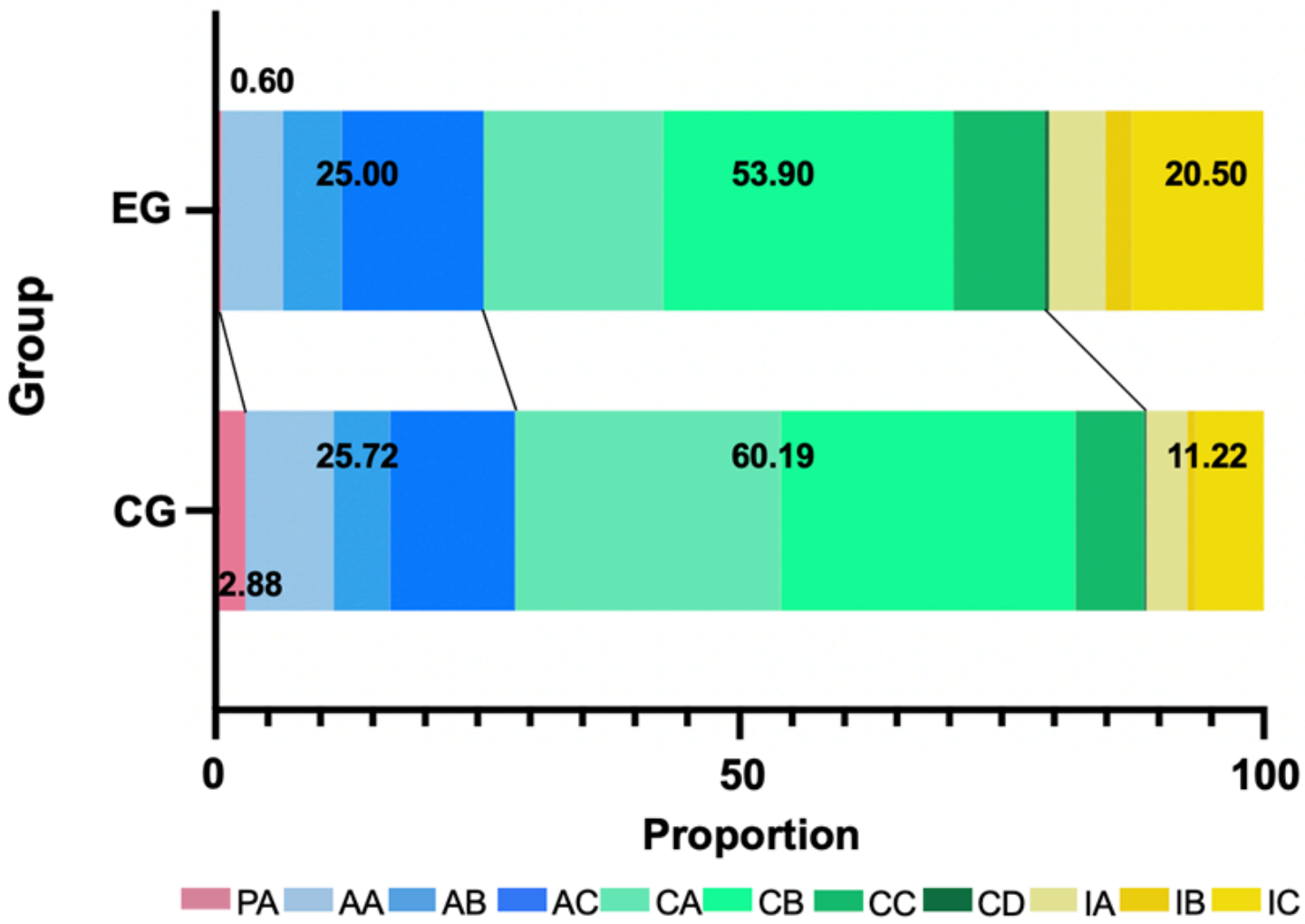


Figure 3

Frequency statistics of cognitive engagement of CE and EG.

Note: PA=Acceptance, AA=Repetition, AB=Emphasize, AC=Summary; CA=Question, CB=Elaboration, CC=Analysis, CD=Contrast; IA=Support, IB=Establishment, IC=Defense.

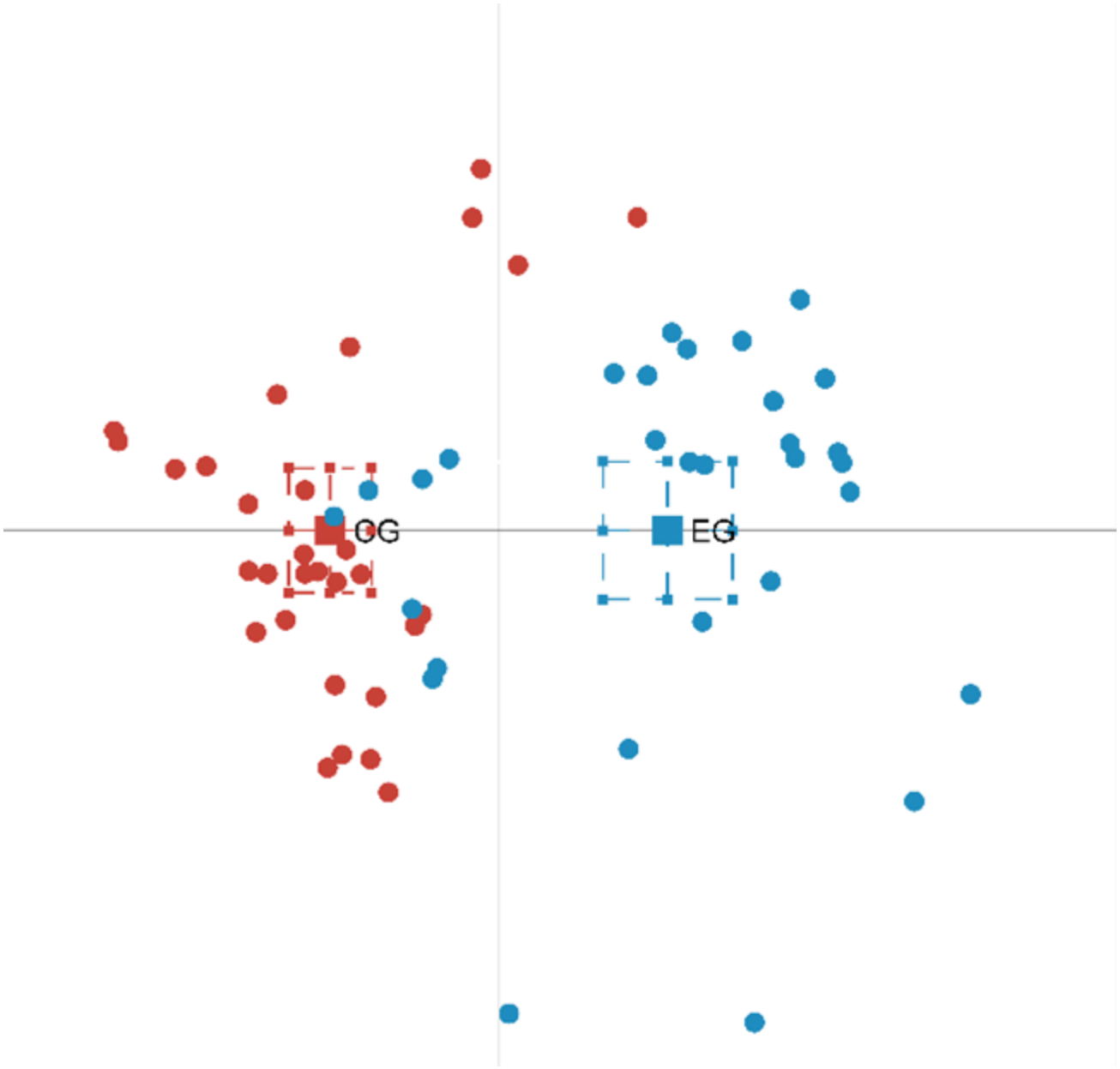
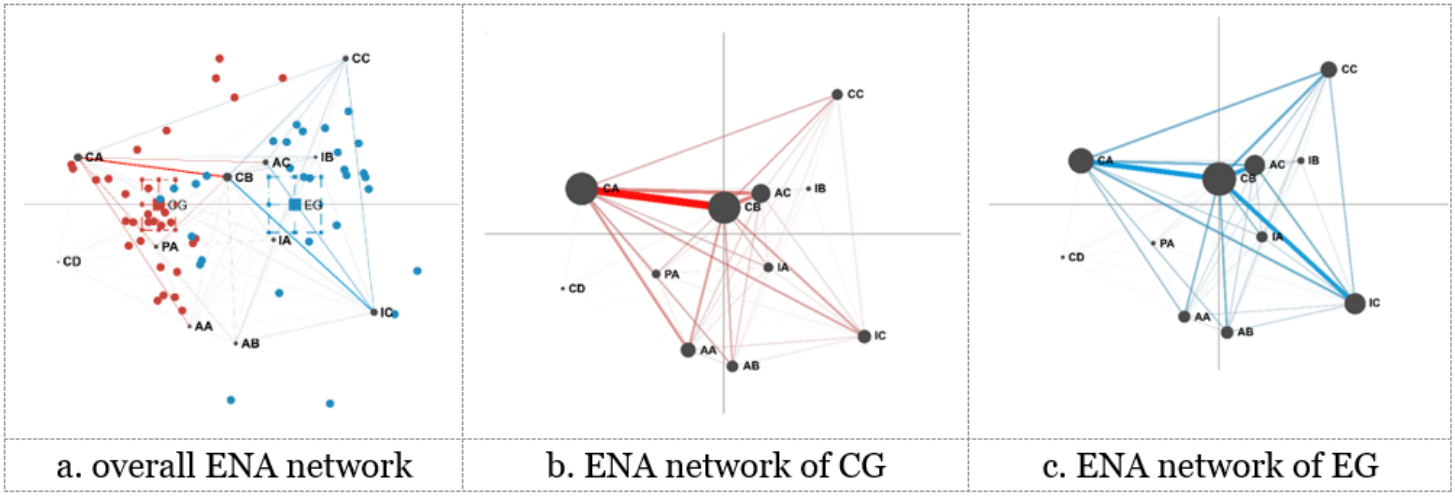


Figure 4

The centroid distribution diagram for the CG and EG.



a. overall ENA network | b. ENA network of CG | c. ENA network of EG

Figure 5

The ENA networks in the CG and EG.

Note: PA=Acceptance, AA=Repetition, AB=Emphasize, AC=Summary; CA=Question, CB=Elaboration, CC=Analysis, CD=Contrast; IA=Support, IB=Establishment, IC=Defense.

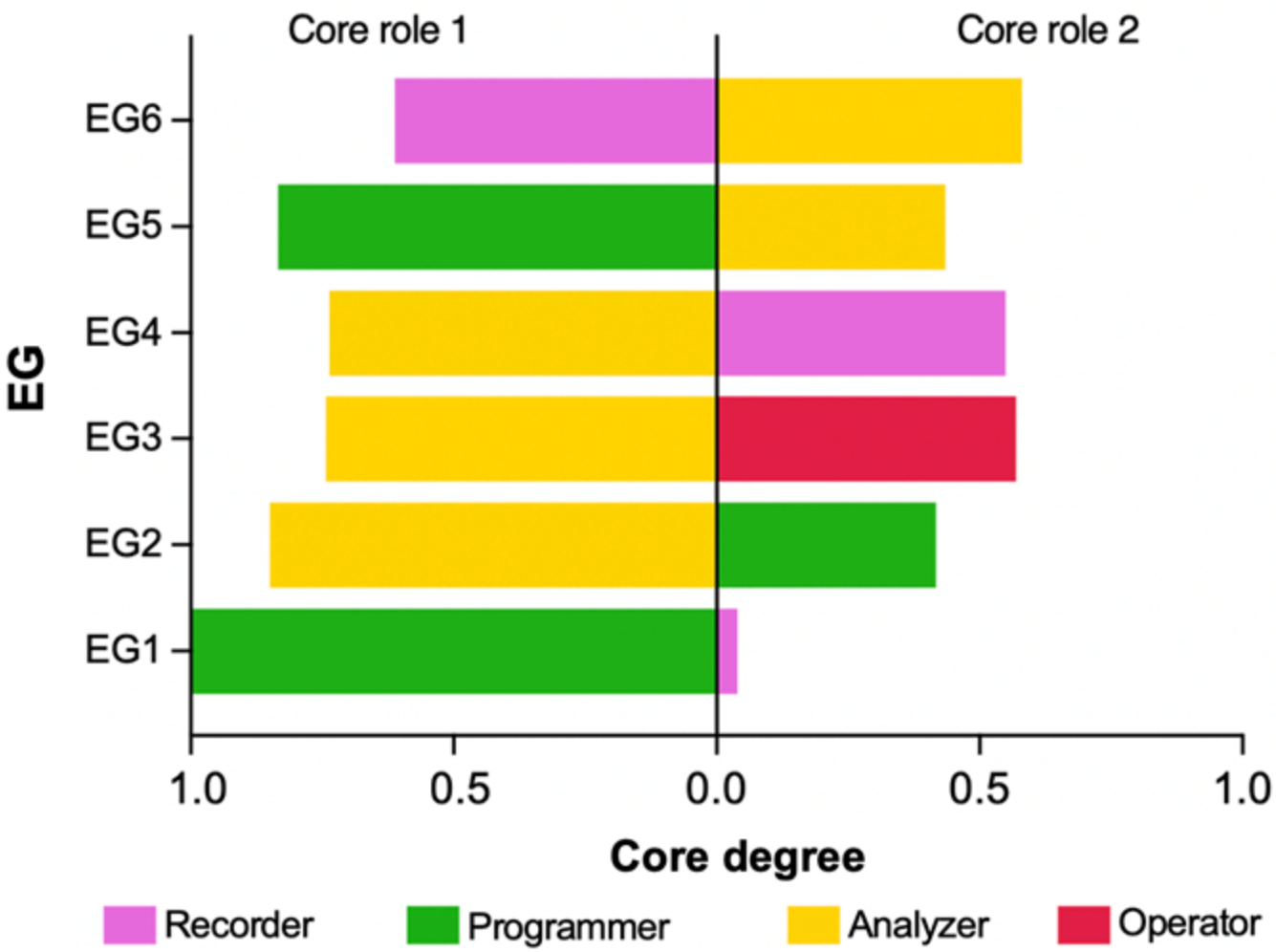


Figure 6

Two core roles of the six experimental groups

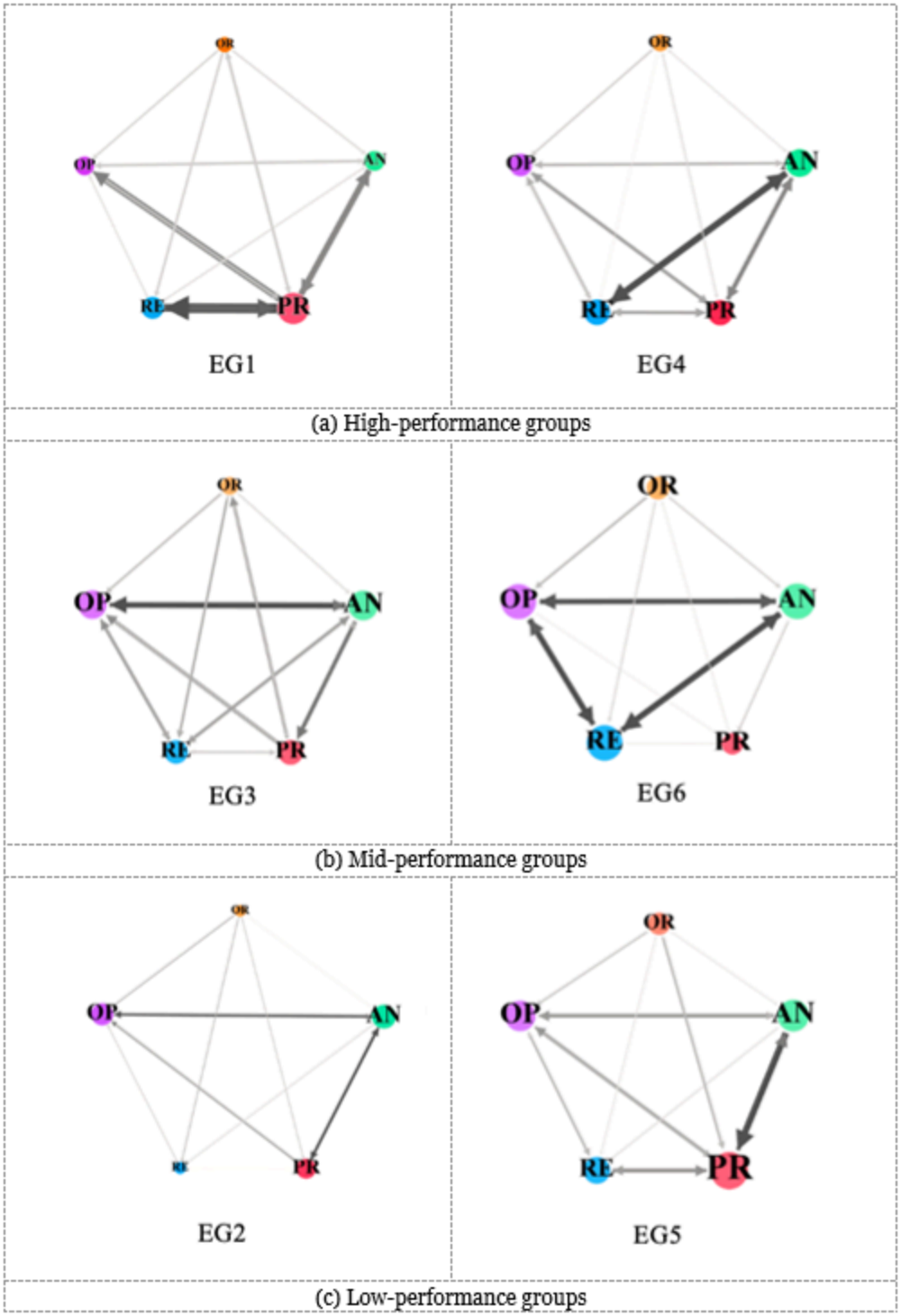


Figure 7

Social network structure diagram of different performance groups

Note: AN=Analyzer, OP=Operator, OR=Organizer, PR=Programmer, RE=Recorder

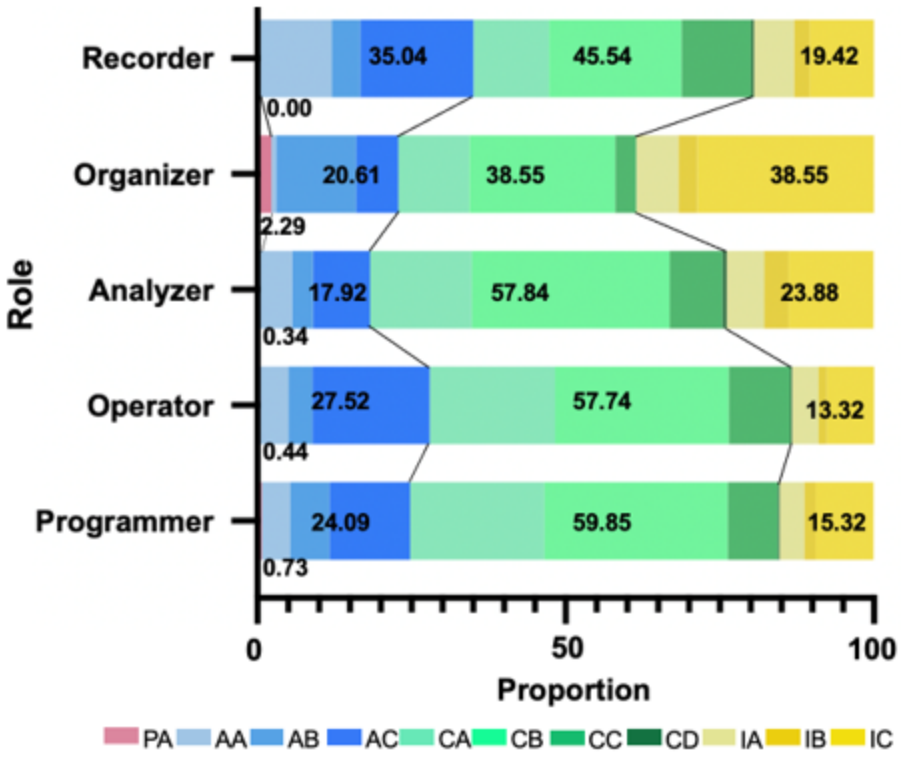


Figure 8

Frequency statistics of cognitive engagement of five roles

Note: PA=Acceptance, AA=Repetition, AB=Emphasize, AC=Summary; CA=Question, CB=Elaboration, CC=Analysis, CD=Contrast; IA=Support, IB=Establishment, IC=Defense.

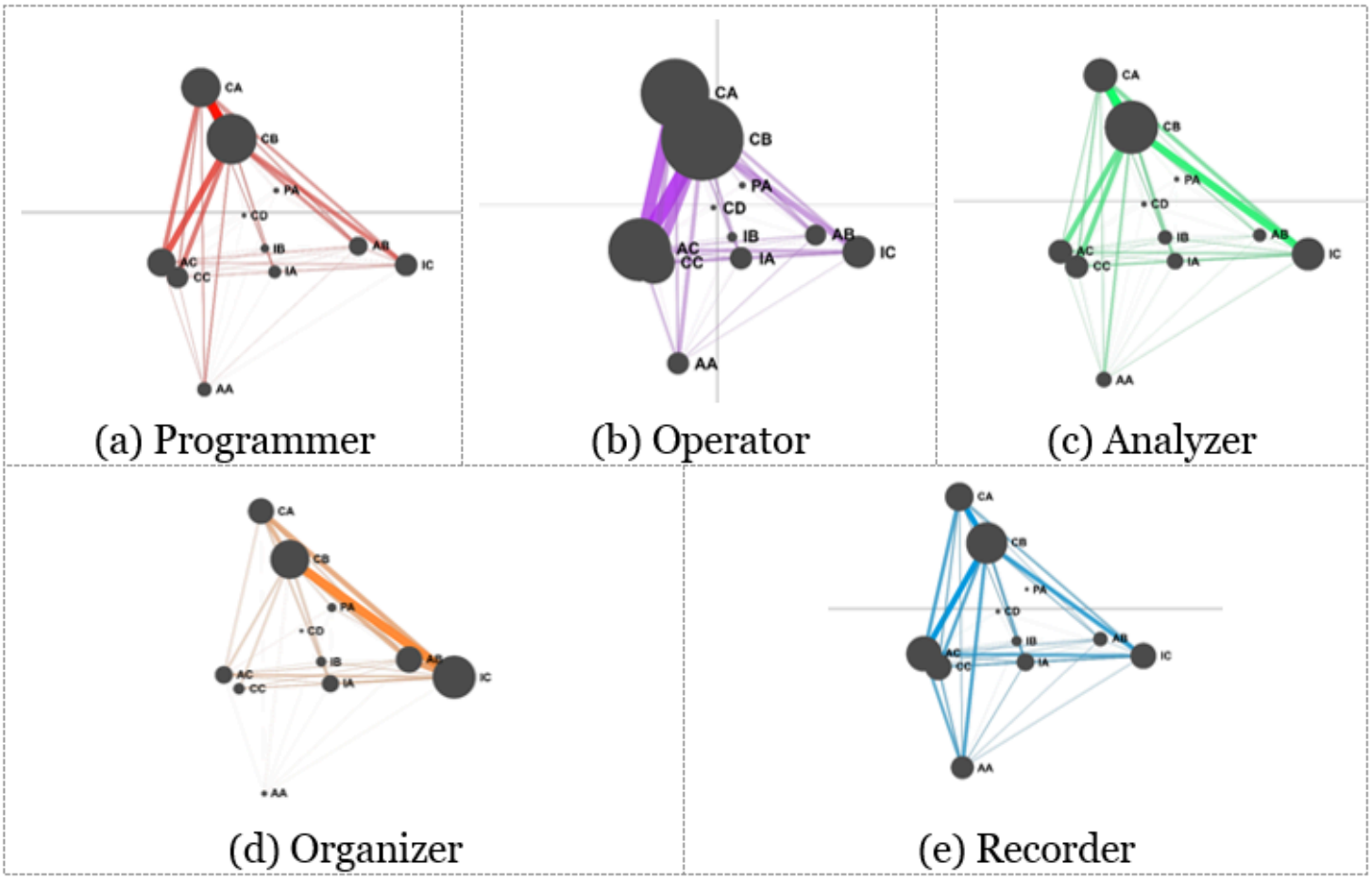


Figure 9

Cognitive network structure diagram of five roles

Note: PA=Acceptance, AA=Repetition, AB=Emphasize, AC=Summary; CA=Question, CB=Elaboration, CC=Analysis, CD=Contrast; IA=Support, IB=Establishment, IC=Defense.